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Study of Two-Phase Microslug Formation in a Microchannel Cross Junction

M. Ryan McDevitt
Darren L. Hitt
Justin W. McCabe

Mechanical Engineering Program
School of Engineering
The University of Vermont

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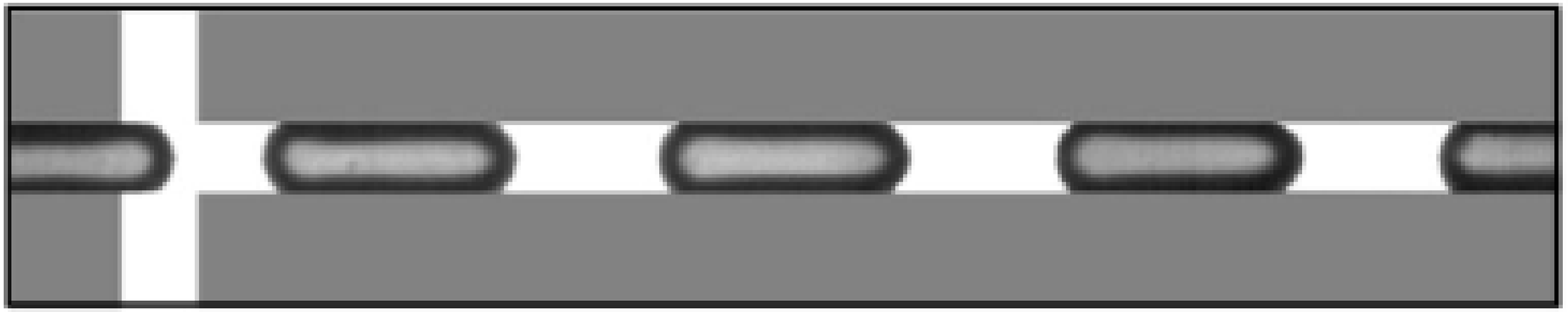
SYNOPSIS

- The slug formation process that occurs at a microchannel junction (Taylor Flow) is used as the basis for a monopropellant throttling system.

- Experimental and numerical techniques have been used to demonstrate the effectiveness, and highlight the key design parameters.



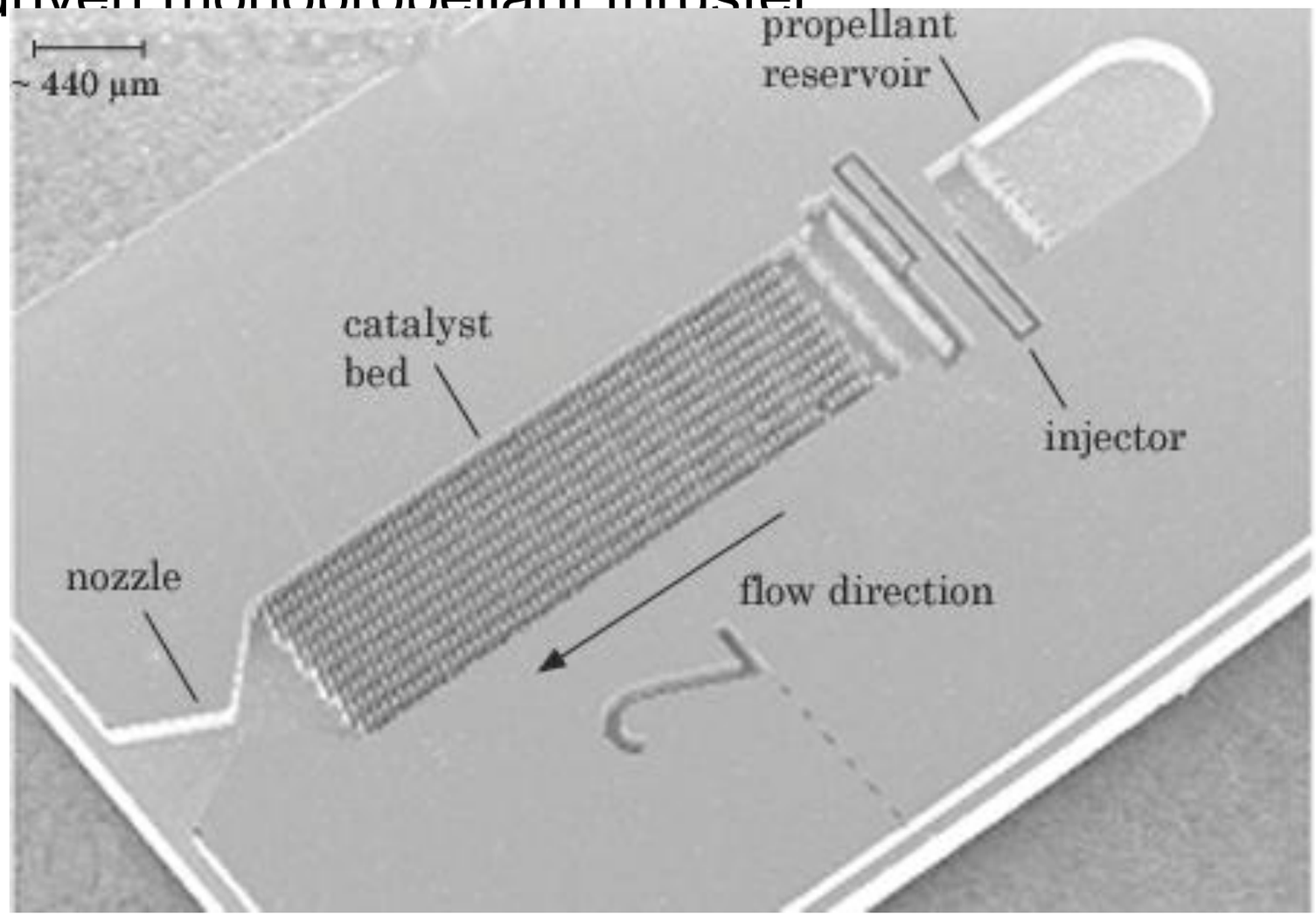
T. Cubaud, M. Tatiseni, X. Zhong and C.M. Ho, “Bubble dispenser in microfluidic devices”, Phys. Review E, 72, 037302, 2005.

OVERVIEW

- Motivation: NanoSat Fuel Delivery System
- Experimental Setup
- Experimental Results
- Numerical Model
- Numerical Results
- Study of Surface Tension Coefficient Effects
- Conclusions

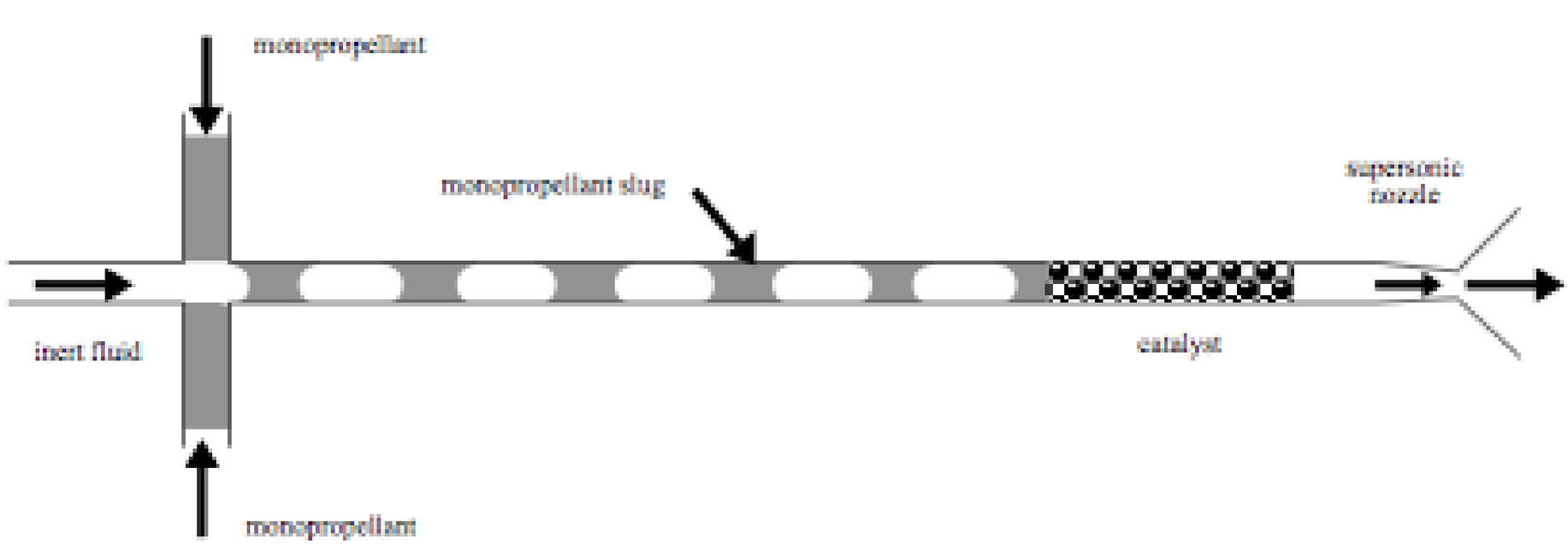
MOTIVATION: NANOSAT FUEL DELIVERY SYSTEM

- NASA and the DoD have an increasing need for „NanoSats" (i.e. <10 kg)
- NanoSats require orbital positioning thrusters capable of 10-100 μN
- To meet this challenge, NASA"s Goddard SFC has proposed a pressure-driven monopropellant thruster

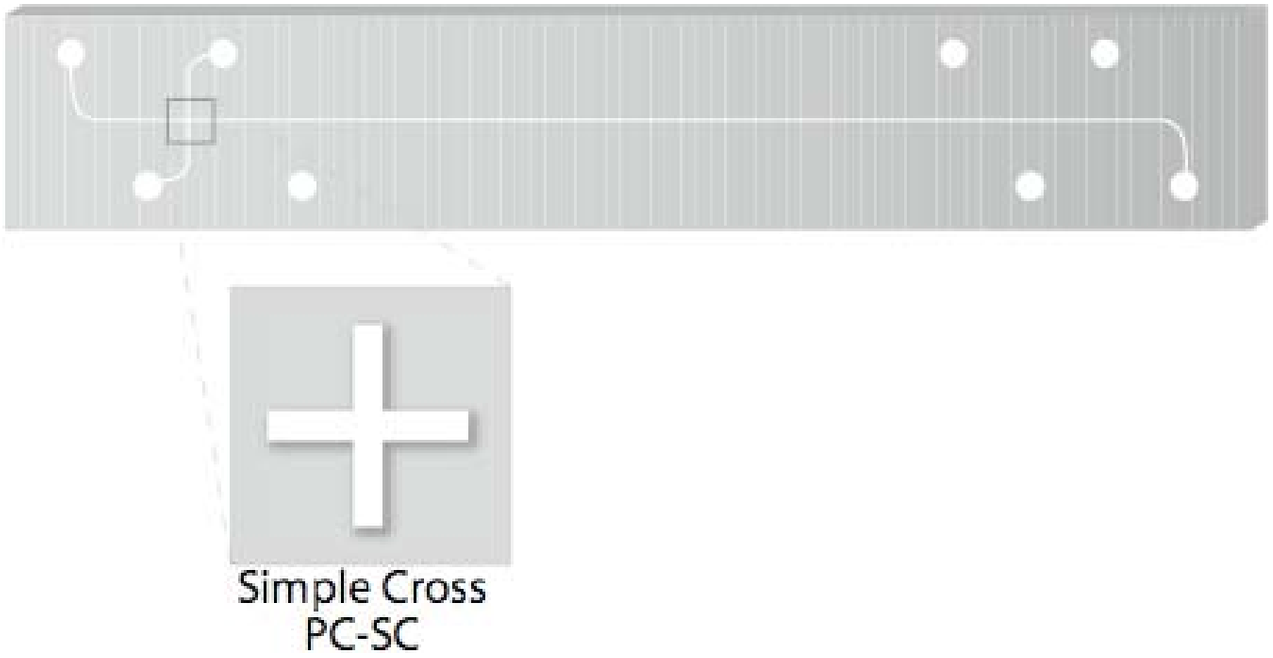


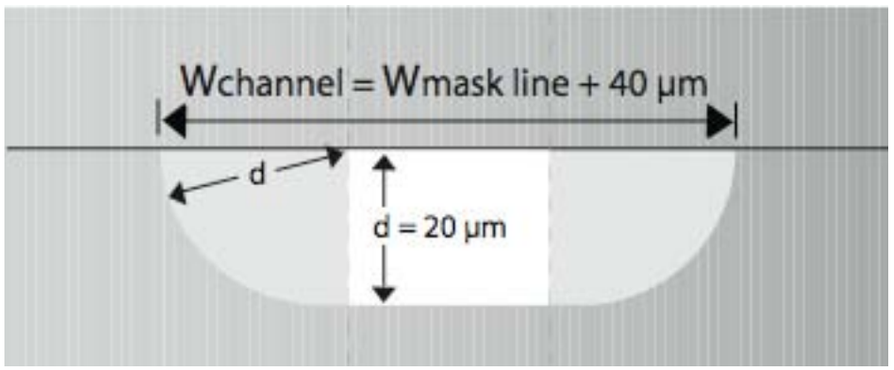
MOTIVATION: NANOSAT FUEL DELIVERY SYSTEM

- One of the engineering challenges with this thruster is controlling the amount of monopropellant
- Typical microvalves lack the actuation control to deliver the impulse bits required for NanoSat control
- To improve the flow throttling, we propose to utilize the slug formation process at a cross junction to generate discrete microslugs of propellant



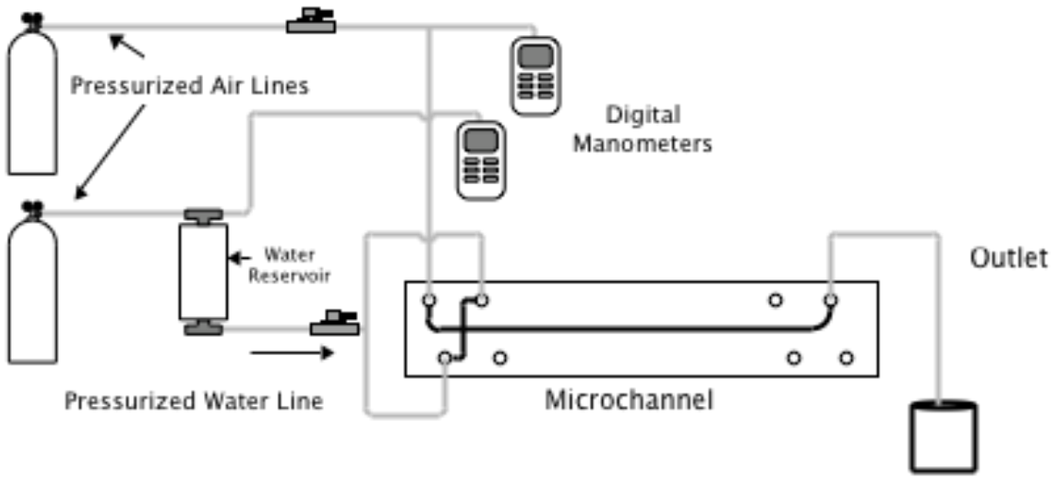
EXPERIMENTAL APPARATUS

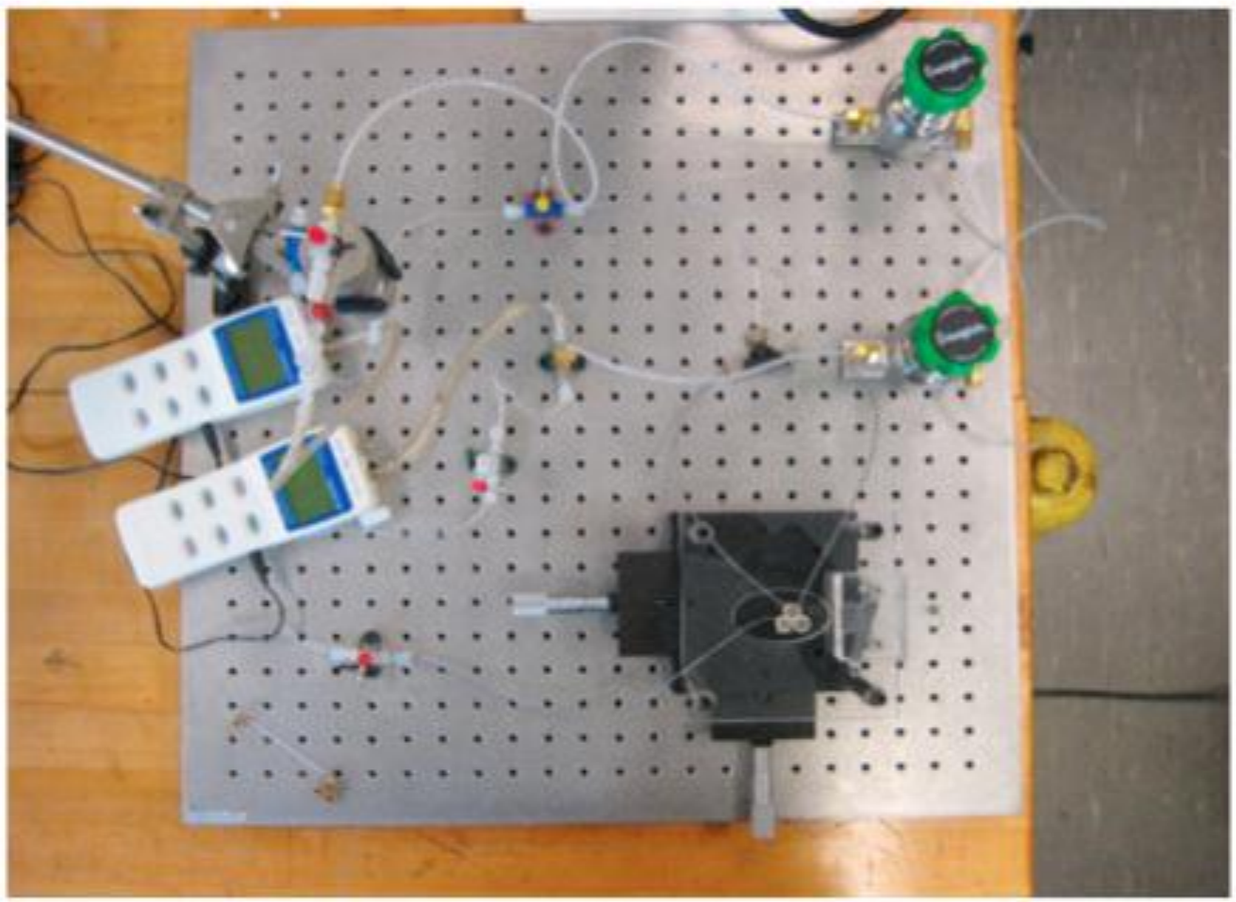




- Micralyne Chip
- 2 Water Inlets
- 1 Air Inlet
- 90° Junction
- 1 Multiphase Outlet
- 50 µm x 20 µm
- O(100 µm)

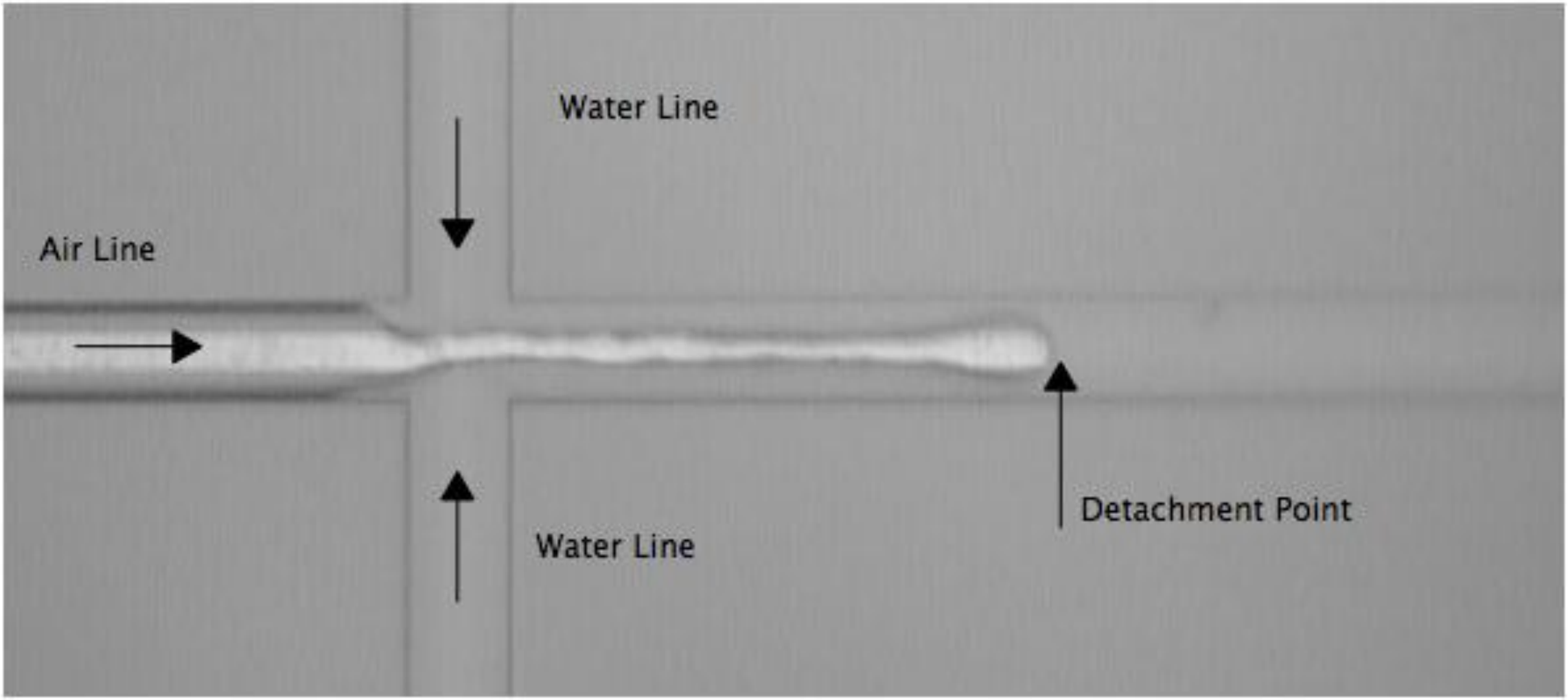
EXPERIMENTAL APPARATUS





- Pressure Driven System
- Control ΔP in .1 psi increments
- Image capture using high speed system capable of 3900 frames per second

IMAGE OF MICROCHANNEL JUNCTION

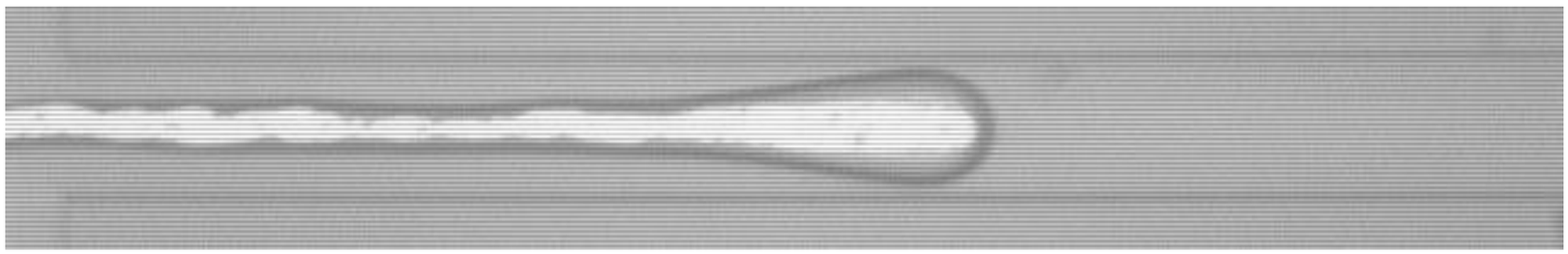


EXPERIMENTAL RESULTS

- At target baseline pressures, flow rate of the target fluid was reduced by up to 50%

- Inlet pressure ratio is the dominant input parameter for controlling slug formation (both frequency and size) but it has limited effect on detachment point

- Surface tension effects play a major role in determining the detachment point



MODELING GOALS

- Accurately capture the physics of the microslug formation
- Predict the volume of droplets generated
- Study the effects of various properties on the slug formation frequency, slug length and detachment point
- Integrate the slug formation model with a chemical reaction model

COMSOL Multiphysics meets these needs using the Level Set Method

LEVEL SET METHOD

What is Level Set?

- Method for tracking interfaces, including multiphase flows
- Implemented in Finite Element codes
- Solves a smooth step function alongside the N-S Equations
- The .5 isocontour of the step function represents the actual interface

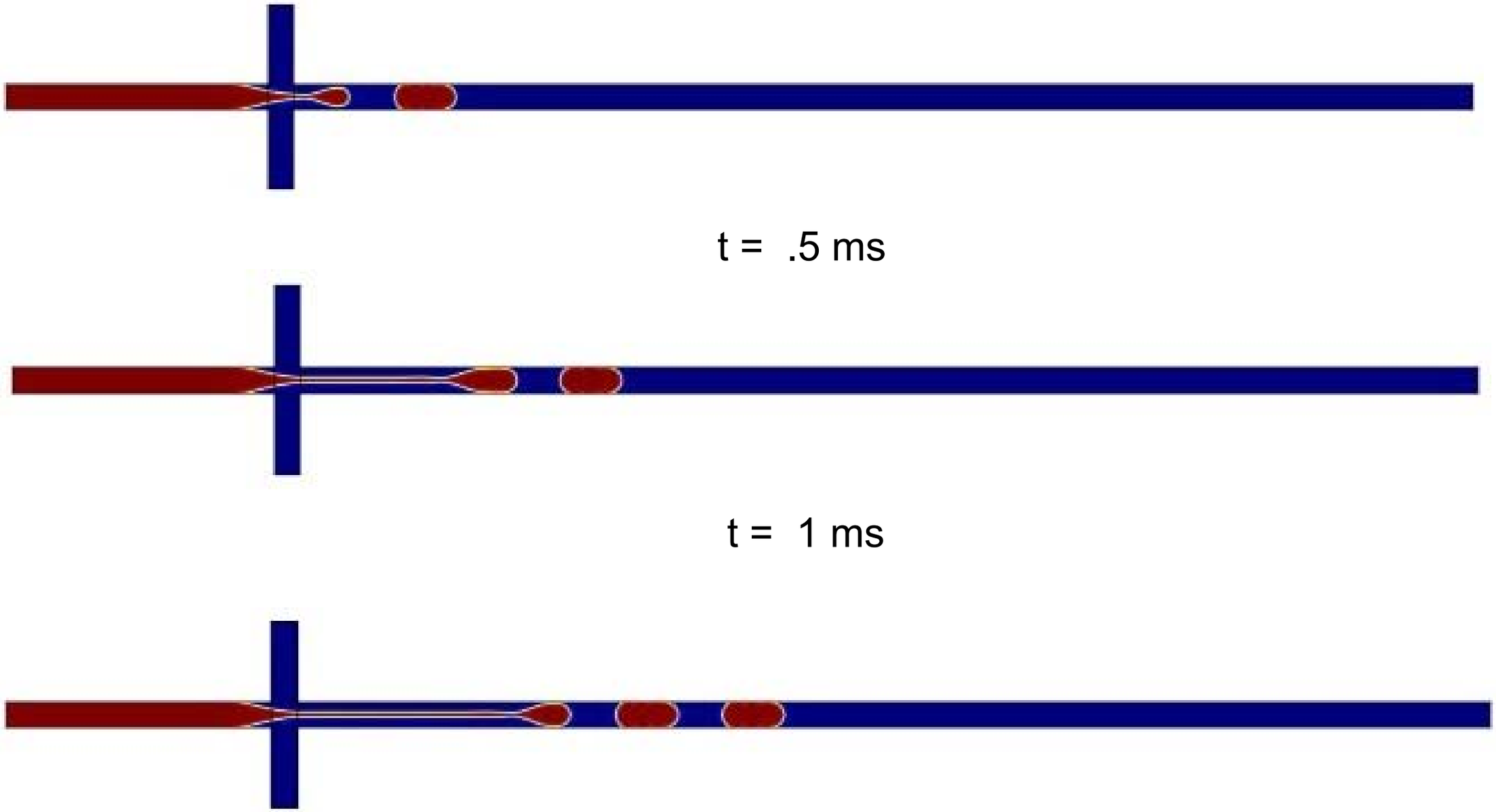
Why do we want to use it?

- Accurately captures the movement of the fluid interface without spurious anomalies
- Integrates easily with chemical reaction modules

NUMERICAL MODEL

- 2D Model with shallow channel approximation (quasi-3D)
- 3 μm quadrilateral (square) elements (187,639)
- 30 psi baseline, 0 psi ratio
- Air @ 20℃
- Water @ 20℃

SIMULATION RESULTS



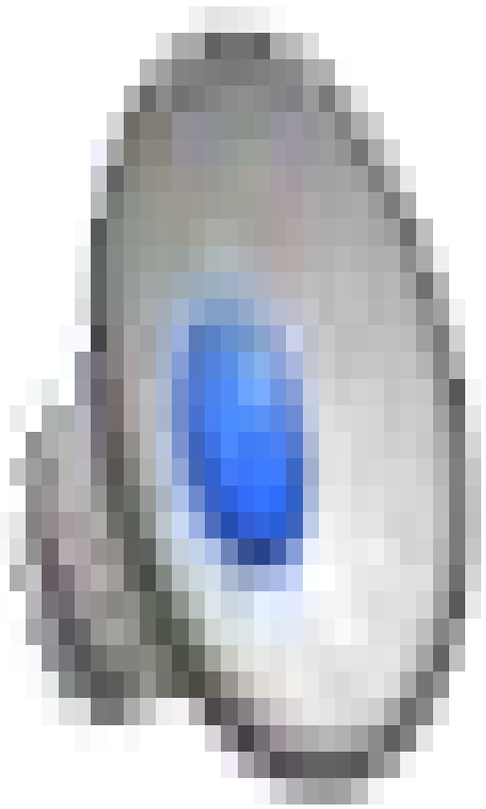
t = .5 ms

t = 1 ms

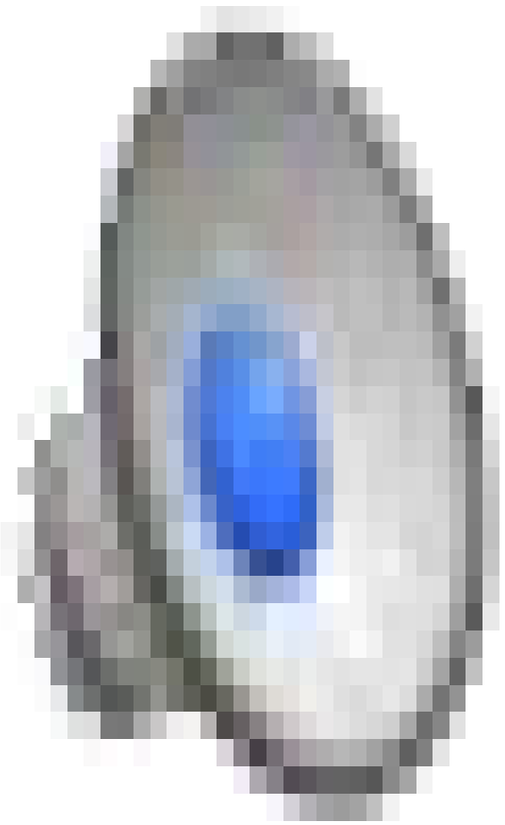
t = 1.5 ms

Red = Air Blue = Water

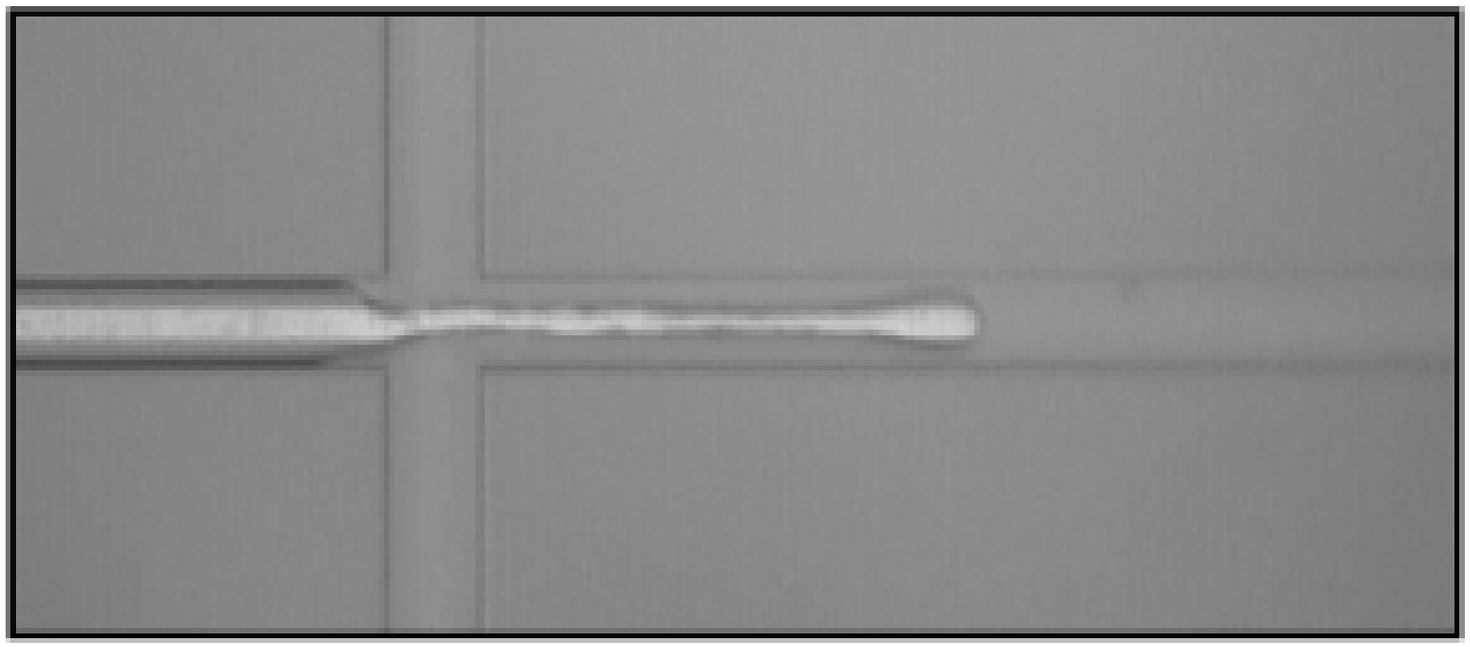
ANIMATION OF SLUG FORMATION

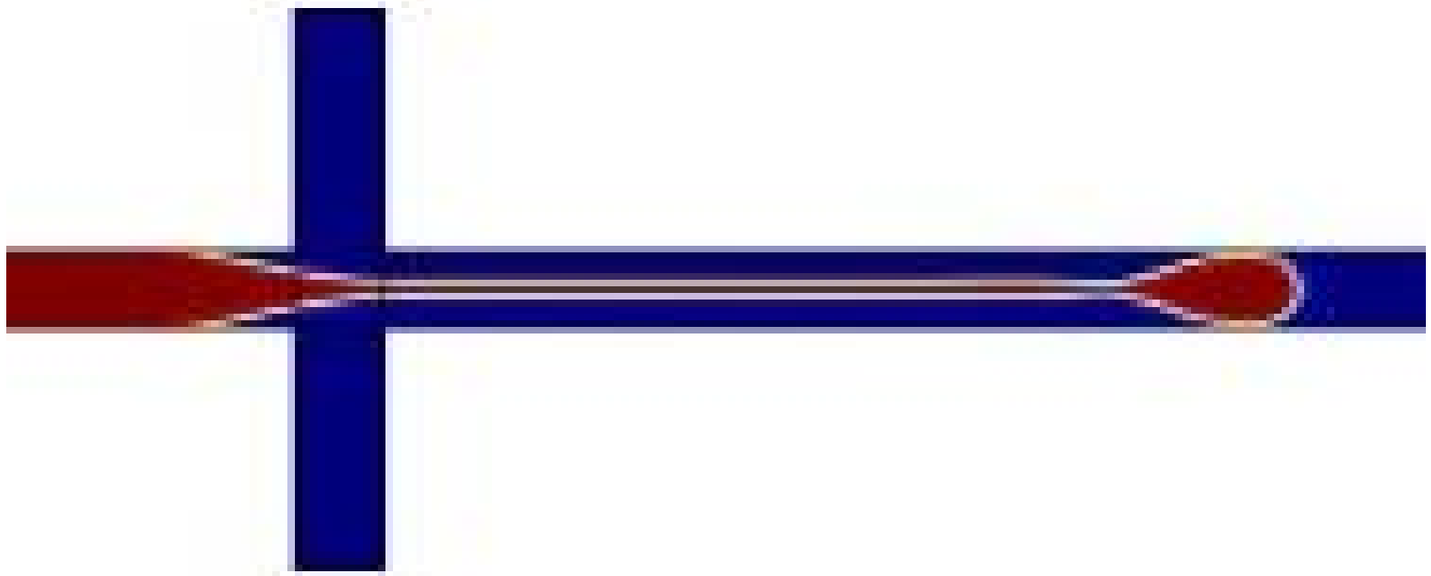


SLUG FORMATION ZOOM

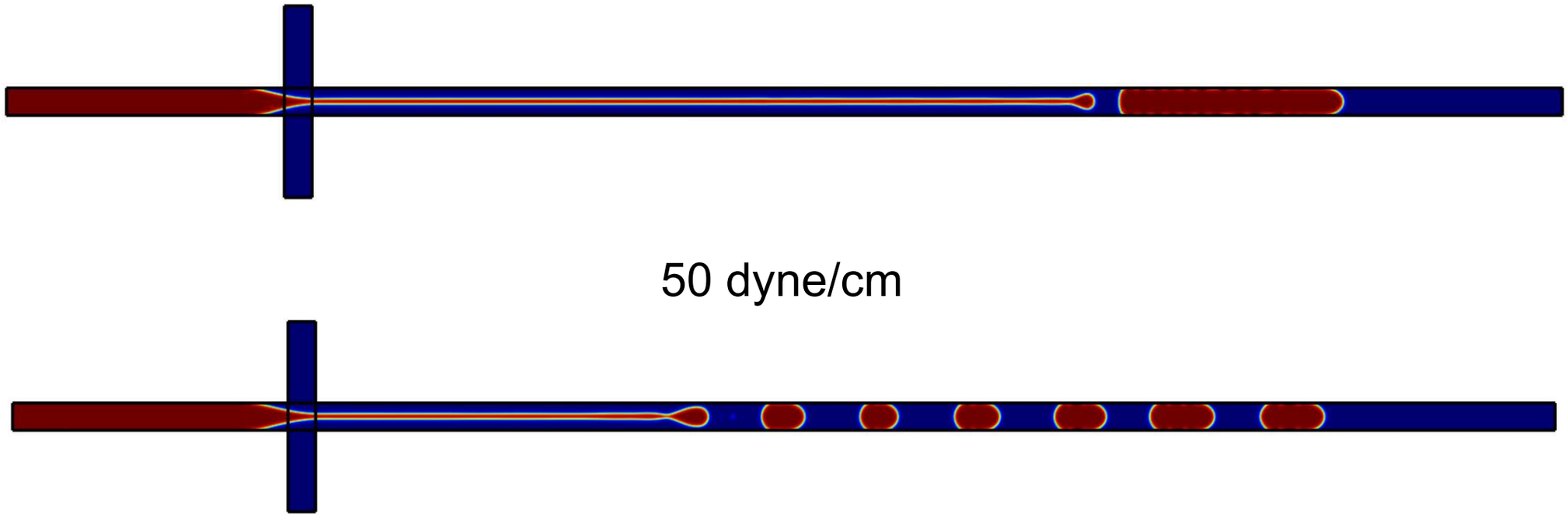


COMPARISON OF EXPERIMENTAL TO SIMULATED RESULTS





EFFECT OF SURFACE TENSION COEFFICIENT



50 dyne/cm

72.8 dyne/cm

100 dyne/cm

CONCLUSIONS

- Microslug formation via a microchannel junction shows promise for micro scale flow throttling
- This phenomenon can be modeled using the level set method
- In addition to slug length and formation frequency, the detachment point is an important design consideration
- Surface tension plays an important role in the detachment point

FUTURE WORK

- Fully 3D simulations
- Couple the slug formation with the catalytic decomposition
- Model transient (i.e. „startup" and „shutdown") effects
- Model impact of droplet formation on thrust characteristics

All of these phenomena can be modeled using COMSOL

QUESTIONS?

Thank you!